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Trends in Aeropropulsion Research and Their Impact on Engineering Education

Louis A. Povinelli and Bruce A. Reichert
Lewis Research Center
Cleveland, Ohio

and

Arthur J. Glassman
University of Toledo
Toledo, Ohio

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Trends In Aeropropulsion Research and Their Impact on Engineering Education

Louis A. Povinelli, Bruce A. Reichert, Arthur J. Glassman*

NASA Lewis Research Center, Cleveland, Ohio

Introduction

This presentation is concerned with the trends in aeropropulsion both in the U.S. and abroad and the impact of these trends on the educational process in our universities. In this paper, we shall outline the new directions for research which may be of interest to educators in the aeropropulsion field. Awareness of new emphases, such as emission reductions, noise control, maneuverability, speed, etc., will have a great impact on engineering educators responsible for restructuring courses in propulsion. The information presented herein will also provide some background material for possible consideration in the future development of propulsion courses. In describing aeropropulsion, we are concerned primarily with air-breathing propulsion; however many observations apply equally as well to rocket engine systems. Aeropropulsion research needs are primarily motivated by technologies required for advanced vehicle systems and frequently driven by external requirements such as economic competitiveness, environmental concern and national security. In this presentation, vehicle based research is first described, followed by a discussion of discipline and multidiscipline research necessary to implement the vehicle-focused programs. The importance of collaboration in research and the training of future researchers concludes this presentation.

Vehicle Based Research

Aeropropulsion technology advancement is implemented at NASA through vehicle-focused programs. Current and future research needs are motivated by five vehicle-focused elements: (1) subsonic transports; (2) supersonic cruise; (3) hypersonic/transatmospheric vehicles; (4) high-performance military aircraft; and (5) small engine technologies for rotorcraft/general aviation aircraft.

Subsonic transports

In the subsonic propulsion regime, emphasis is on the development of more efficient engines. Figure 1 shows the propulsive and thermal

efficiency improvements that have been achieved since the development of jet propulsion and the resulting overall efficiency. Future improvement in propulsive and thermal efficiency will be achieved through ultra-high-bypass ratio cycles and high-efficiency cores. The goal of both programs is to improve the overall engine efficiency within the limitations of aircraft noise and emission restrictions.

The technology for fuel-efficient, unducted, advanced turboprops has been demonstrated. Ducted prop/fan configurations suitable for large wide-body aircraft powered by two large-thrust engines mounted under the wing are being investigated. NASA has chosen a noise level goal for new ultra-high-bypass technology that will result in an effective perceived noise level (EPNL) of 10 EPNdb lower than noise levels required by current FAR 36, Stage 3 regulations.

High-efficiency core investigations center around improving thermal efficiency by increasing core pressure ratios and temperatures. Higher combustor temperature and pressure will increase the potential to create NO_x in the combustion process. Specific goals for NO_x emission have not been set. However, cleaner combustion techniques must be developed that will maintain or reduce current NO_x emission levels under the more demanding conditions of higher combustor temperature and pressure.

Supersonic cruise

For commercial supersonic flight, most of the research activity today is focused on demonstrating that the environmental issues of NO_x emissions and noise are acceptable and non-damaging. Within NASA, the first phase of the high speed research program (HSRP) must demonstrate that the environmental concerns are met.

* University of Toledo Resident Research Associate

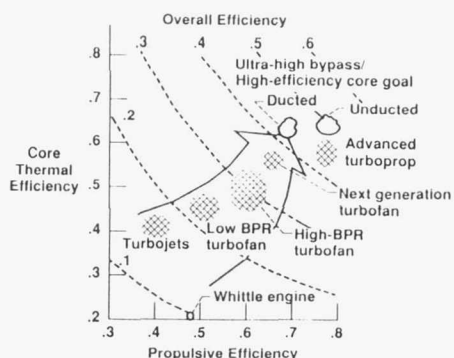


Fig. 1 Subsonic propulsion efficiencies

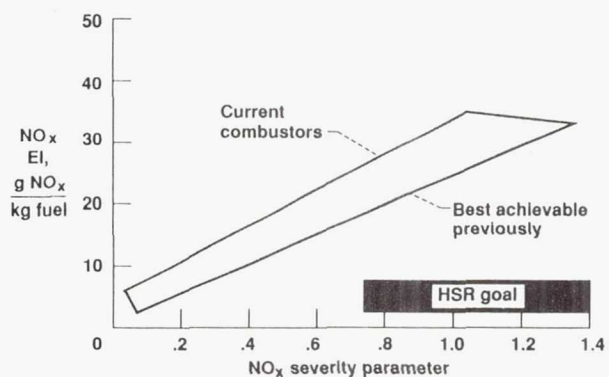


Fig. 2 NO_x emission

The magnitude of the NO_x emission challenge is evident in Figure 2. Plotted is the NO_x emission index (EI), expressed in terms of grams NO_x emission per kilogram of fuel burned, against the NO_x severity parameter, a measure of combustion conditions that depend on pressure and temperature. The HSRP goal represents a four-fold reduction in NO_x emission compared to the current best performance achieved in the NASA/GE Experimental

Clean Combustor Program. The jet exhaust noise presents a substantial challenge to the HSRP, as well. The goal of satisfying FAR 36, stage 3 regulations will require developing nozzles that generate noise levels 15 to 20 db less than simple conical nozzles while maintaining acceptably high overall thrust levels.

Long-term research related to the HSRP to develop a propulsion system based on supersonic through-flow technology continues. The objective of current studies, shown in Figure 3, is to demonstrate the viability of establishing and maintaining supersonic flow through a fan stage and finding appropriate inlet and nozzle configurations for a supersonic through flow fan.

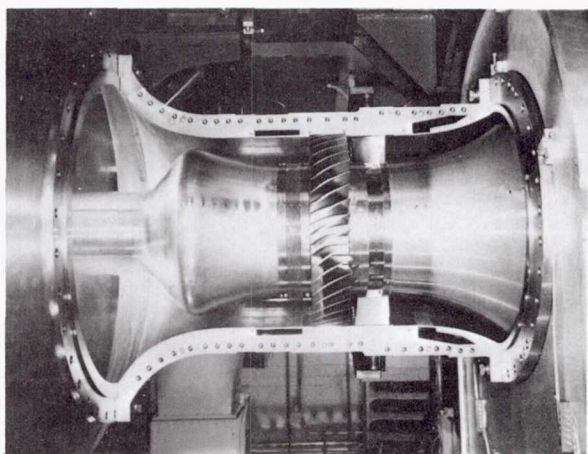


Fig. 3 The supersonic through flow fan

Hypersonic/transatmospheric vehicles

The goal of the National Aerospace Plane (NASP) program remains to develop a single stage-to-orbit vehicle using air-breathing propulsion. This will require supersonic combustion ramjets for propulsion which use liquid or slush hydrogen as fuel. Studies have shown that the engine must be carefully integrated with the vehicle, as shown in Figure 4, and will utilize the cryogenic temperature hydrogen fuel for cooling.

The ability to produce, transfer, and store slush hydrogen has been demonstrated. Wind tunnel tests of inlet configurations have been conducted and a hydrogen fueled ramjet has been constructed and operated to investigate engine operability and control. Many challenging technical issues still require solutions before the NASP will fly.

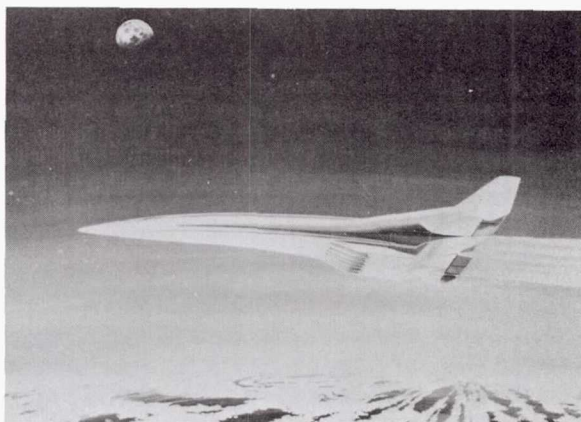


Fig. 4 Conceptual drawing of the National Aerospace Plane (NASP)

In addition, propulsion systems for flight in the Mach 4 to 6 range are being studied under the NASA/Air Force High Mach Turbine Engine (HiMaTE) program. This program is centered on turbomachinery-based combined cycle engines. Conceptual design studies of two configurations, the turboramjet and the air-turboramjet are being conducted. Both configurations operate as ramjets at high speed, with air either bypassing or windmilling through the turbomachinery.

High-performance military aircraft

In the military arena, research is directed towards developing propulsion systems for highly maneuverable aircraft and supersonic Short Take-Off/Vertical Landing (supersonic STOVL) aircraft, Figure 5. Concepts that have been studied to improve maneuverability include inlets capable of operating at high angles of attack and multi-axis thrust vectoring nozzles.

Engine research related to improving maneuverability is being conducted under the NASA/DOD Integrated High Performance Turbine Engine Technology (IHPTET) program. The goal of IHPTET is to double the engine thrust-to-weight ratio. This goal will be achieved, in part, by operating at higher combustor temperatures.

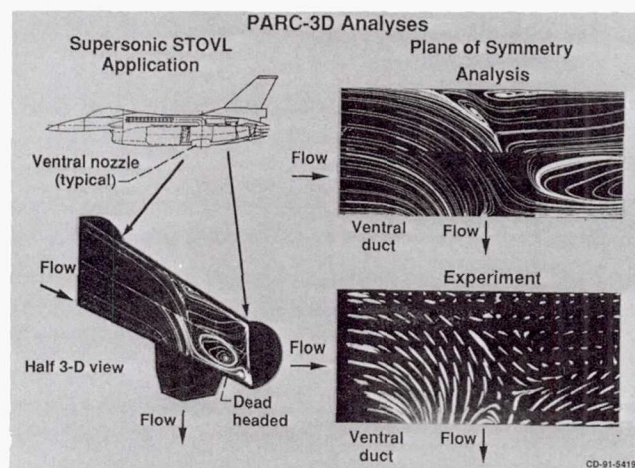


Fig. 5 Supersonic Short Take-Off/Vertical Landing (supersonic STOVL) nozzle analysis

Rotorcraft/general aviation aircraft

Three goals of NASA research in rotorcraft and general aviation propulsion are: (1) to reduce fuel consumption of small engines by 30%; (2) to develop lighter, quieter, and more reliable transmissions; and (3) to achieve high speed ($M = 0.8$) rotorcraft capabilities.

The improvements in small engine fuel economy will be achieved through increases in engine pressure and temperature operation. The objective of the NASA/Army Advanced Rotorcraft Transmission (ART)



Fig. 6 The V-22 Osprey high-speed rotorcraft

program is to develop drive train systems for the next generation of rotorcraft that are 25% lighter and 10 db quieter than current systems, while increasing reliability to 5000 hours mean operating time between removal. High-speed rotorcraft, like the V-22 Osprey shown in Figure 6, may, in the future, be an important component in the US air transportation system. At a speed of 450 knots, these aircraft could serve as primary intercity vehicles. Propulsion system weight reduction is critical to achieving higher speeds.

Discipline Research

The objective of discipline research is to build the foundation of understanding needed to support the development of the vehicle based technologies. Two common goals span the breadth of the vehicle based research described here: to operate engines at higher pressures and temperatures and to achieve greater efficiency and aircraft speed while maintaining or improving environmental acceptability. For each of the basic disciplines, these twin goals pose unique challenges.

Internal fluid mechanics

Future engines will require lower NO_x emission and jet noise levels to be environmentally acceptable. In order to attain this goal and to improve engine performance we must increase our understanding of chemically reacting flows, internal flows through ducts and turbomachinery, and free shear layer flows. The research emphasis has been on improving the numerical simulation of engine system fluid mechanics. The principal objective is to develop computational fluid dynamic tools that will hasten advancements in propulsion system performance and capability and reduce the cost required for the engine development cycle.

Because of their complexity, calculation of these flows requires modeling of some phenomena in place of direct calculation. Even with the remarkable improvements in computational technologies, the use of modeling is, and will continue to be, necessary. Accordingly, much experimental, analytical and numerical effort is directed towards improving models of transition, turbulence, chemical kinetics, acoustics, and multiple phase flows. Likewise, experimental studies will continue to proceed apace with code development. These will serve as an adjunct to the understanding, assessment, and validation of numerical prediction. For example, Figure 7 shows a comparison of experimental data and numerical prediction of flow within the blade passage of a centrifugal compressor.

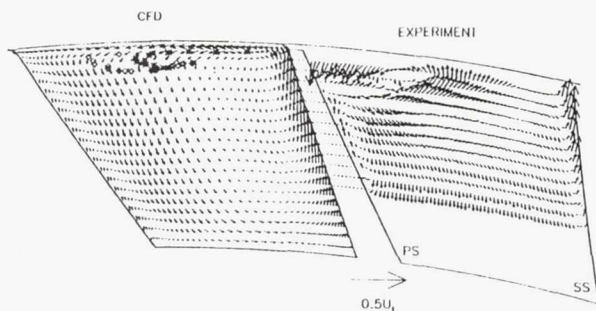


Fig. 7 Experimental data and numerical prediction of flow within a centrifugal compressor blade passage

Materials

Future advanced engines systems will not fly without advanced materials. Achieving the goals established for future engines will require materials that are lighter, operate at higher temperature, and last longer than materials presently used. The balance struck between these three requirements depends upon the vehicle application. Materials intended for future engines for civil transportation aircraft will require material lives a hundred times longer than those intended for the NASP, where

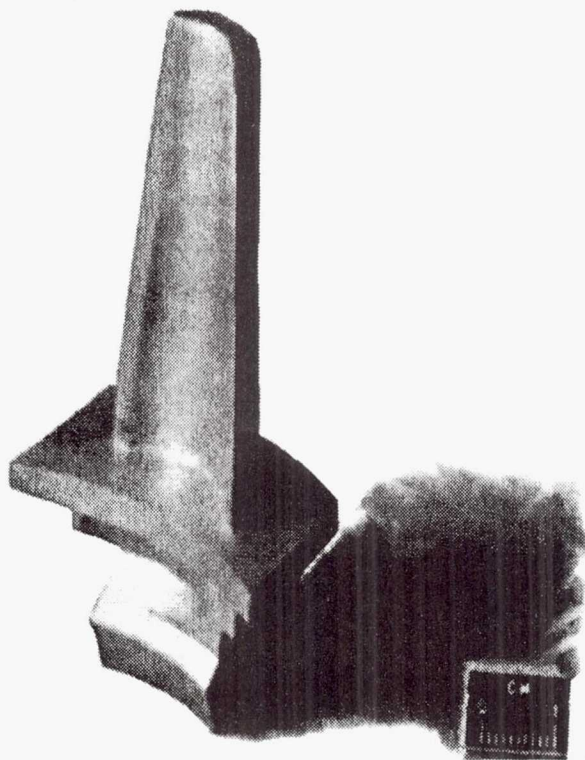


Fig. 8 A matrix metal composite (MMC) turbine blade

temperature will be significantly higher. Within vehicles, the required properties of materials vary from component to component. This wide range of requirements dictates an approach that explores many materials alternatives.

Emphasis is being placed on polymer matrix composites (PMC's) for potential use in fans, casings, and engine control systems. Intermetallic/metal matrix composites (IMC's/MMC's) are under investigation for application in such areas as compressor and turbine disks, blades (shown in Figure 8), and vanes, and in the exhaust nozzle. For extremely high temperature applications, ceramic matrix composites (CMC's) are being explored. Initial applications may include liners for the combustor and exhaust nozzle and turbine vanes and ultimately turbine blades and disks.

Lubrication technology is also challenged by the envisioned higher engine operating temperatures. High temperature lubricants will also minimize engine weight by their reduced need for engine oil coolers. In the area of liquid lubricants, investigators are studying the reaction mechanisms that contribute to lubricant decomposition. Improving the strength of solid lubricants that would be utilized as bearings is also being explored.

Structures

The operating conditions of future engines and their construction from new composite materials pose many technical challenges for the engine structures researcher. Within turbomachinery, large rotational kinetic energies can couple with vibration modes and result in large vibrations or dynamic instabilities. Complex physical interactions are imposed on engine structures by thermal and aerodynamic loading. New composite materials exhibit properties that depend not only on the properties of each composite constituent, but also on factors such as bonding at the constituent interface and the influence of microcracking.

The objective of structures research continues to be the development of numerical methods to predict and control the global behavior of engine structures. Experimental and numerical effort is required to improve constitutive modeling as well as fatigue and fracture analysis of new composite materials. Improvements in computational techniques

are necessary to allow closer coupling of aerodynamic and structural predictions, as depicted in Figure 9. Probabilistic analysis and design methods are being investigated that account for statistical variations of all relevant factors and result in an assessment of structural performance, life and reliability. Active control techniques are being explored as a method to minimize shaft vibration in turbine engines.

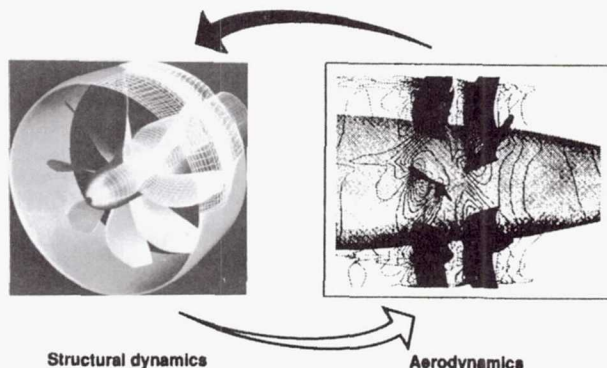


Fig. 9 Aeroelastic methods coupling structural dynamics and aerodynamics

Instruments and controls

To calibrate and validate numerical aerodynamic, combustion chemistry, heat transfer and structural dynamic predictions will require experimental methods that are capable of acquiring data in greater detail, more accurately and under more realistic (and hostile) conditions than is possible with current methods. Laser based techniques to measure velocity are well established. The purpose of continued research is to extend laser techniques in order to obtain flow temperature, pressure, and species concentration. Measuring heat transfer and strain of engine components at high temperatures is also a subject of current research. One approach is to improve contact sensor technology (i.e., surface heat flux and strain gages) by constructing thin, sputter-deposited film gages, along with appropriate substrate material, directly onto experimental hardware. A second approach to strain measurement is a laser speckle technique, shown in Figure 10, that measures the difference in speckle patterns produced by reflected laser light upon the unstrained and strained specimen in order to calculate strain.

Gains in propulsion reliability, performance, and reduction in the weight of future engines will be obtained, in part, by improvements in propulsion control systems and the integration of airframe and propulsion

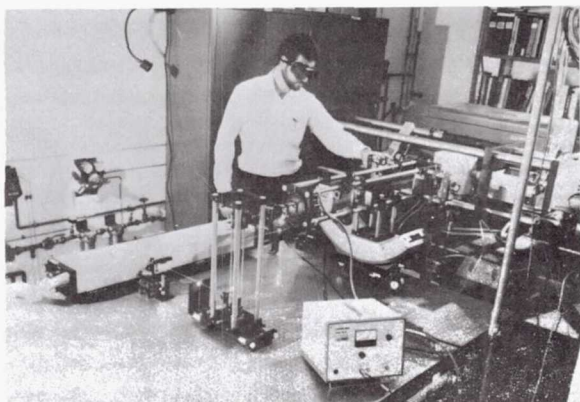


Fig. 10 Laser speckle strain measurement system

controls. In the near term, much work has been directed toward developing fiber-optic based sensors and controls systems. More research in this area is needed to extend the temperature range of current fiber-optic controls technology to accommodate sustained operation in the supersonic and hypersonic flight regime. For the NASP, work is directed toward developing simple, transient models of the propulsion systems to identify and resolve operability problems and to serve as a basis for engine controller design. Developing control strategies to respond to inlet unstart are critical.

Multi-Discipline Technology

The increasingly sophisticated analyses required for propulsion systems require increasing reliance on interdisciplinary research. Two such programs are described next. The ultimate long-term objective is to combine the discipline activities in order to produce validated multi-disciplinary numerical codes to simulate complete propulsion systems.

Integrated High Performance Turbine Engine Technology

IHPTET, briefly described earlier, is a collaboration between NASA, DOD and industry to double propulsion system capability. IHPTET is primarily a program that seeks to synergistically combine the individual discipline research activities in the areas of instrumentation, materials, structures and computational fluid dynamics and the individual engine component technologies in the areas of compressors, combustors, turbines, nozzles, controls, and mechanical systems.

Numerical Propulsion System Simulations

The cost of implementing new technology in aerospace propulsion systems is becoming extremely expensive. One of the major reasons for the high cost is the need to perform many large scale system tests. Extensive testing is used to capture the complex interactions among the multiple disciplines and multiple components inherent in complex systems. The objective of the Numerical Propulsion System Simulation (NPSS) is to provide insight into these complex interactions through computational simulations. This will allow for comprehensive evaluation of new concepts earlier in the design phase before a commitment to hardware is made. It will also allow for rapid assessment of field-related problems.

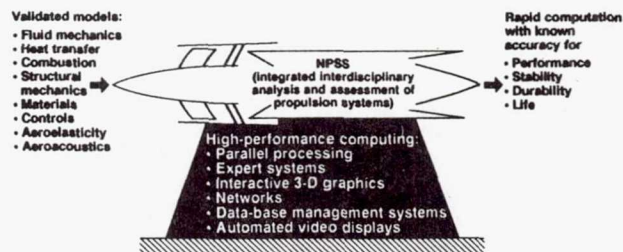


Fig. 11 Numerical Propulsion System Simulation (NPSS)

The NPSS approach, illustrated in Figure 11, means the coupling of disciplines and components computationally to determine system attributes such as performance, reliability, stability, and life. Since these systems attributes have traditionally been obtained in the test cell, NPSS is referred to as the "numerical test cell". Such an integrated interdisciplinary system analysis requires advancements in the following technologies: (1) interdisciplinary analysis to couple the relevant disciplines such as aerodynamics, structures, heat transfer, chemistry, materials, controls; (2) integrated system analysis to couple subsystems, components, and subcomponents at an appropriate level of detail; (3) high performance computing platforms composed of a variety of architectures, including massively parallel processors, to provide the required computing speed and memory; and (4) a simulation environment that provides a user-friendly interface between the analyst and the multitude of complex codes and computing systems that will be required to perform the simulations.

Partners in Aeropropulsion

The increasing complexity and expense of propulsion systems, along with the need for interdisciplinary analysis, brings the necessity for increased cooperation among government agencies, industry, and academia. At Lewis Research Center, the NASA staff works as a team with the co-located Army Propulsion Directorate and the on-site support service contractors. Many of our programs require us to work cooperatively with the other NASA aeronautics centers, who provide the advanced vehicle technology. We also interact and cooperate with the Department of Defense, whose armed services all have needs and programs for advanced propulsion technology. Our interaction with the Federal Aviation Administration concerns safety and environmental issues.

The collaboration between NASA and educational institutions has been particularly fruitful. We will continue to strengthen our partnerships with industry and academia. One such program is the Ohio Aerospace Institute, a public-private educational consortium of nine Ohio universities, NASA Lewis, Air Force Wright Laboratories and private industry. The NASA aeronautics program devotes approximately ten percent of its research and development resources to support the nation's universities, the major portion of which is for basic research grants. Other education programs in which NASA participates include the ASEE Summer Faculty Fellowship Program, the National Research Council (NRC) Resident Research Associateship Program, the NASA Graduate Students Research Program, the Space Grant program, the University Advanced Design Program, Cooperative Education

and Summer Internship Programs for undergraduates, the establishment of Research Institutes such as ICOMP, the Institute for Computational Mechanics in Propulsion and the Center for Modeling of Turbulence and Transition at Lewis, and Joint Institutes at the NASA Research Centers and the establishment of Centers of Excellence at specific universities.

Conclusion

Given the scenario described in this presentation, one may now look at the curricula within our engineering colleges to determine the state of readiness or preparation of graduating seniors for entry in propulsion research. In order to be in a position to contribute to the on-going efforts, one must be well versed in the classical skills taught at the universities. However, it has become increasingly important that training be sufficiently broad so as to encompass experimental as well as computational skills. Understanding physics from an analytical, numerical and experimental viewpoint provides the researcher with a greater arsenal of tools which with to perform research. This new prototype, therefore, stands on a foundation which allows him or her to address a particular research area from complementary directions, where one tool provides the missing information not available from another tool or viewpoint. Today, we have too few people with this broad capability involved in our research activities. As we look to the future however, we are confident that the interdisciplinary skills will gradually evolve within the engineering curricula of our nations universities.

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